CONVERSION OF SOLID FUELS TO LOW BTU GAS

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BACKGROUND AND INTRODUCTION

More than 11,000 gas producers were in operation during 1926, gasifying about 15 million tons of coal per year into low BTU gas. This fuel served both industrial and town requirements with approximately 50 percent utilized by the steel industry alone. In special cases the producer gas was cleaned by methods commonly used for purifying coke oven gas and water gas. The industrial success of making a clean, desulfurized manufactured gas from coal was apparent.

The current energy and environmental crises should not seem possible to those unfamiliar with the further history of coal gasification. However, this reveals that the 11,000 gas producers operating in 1926 decreased to about 4,000 in 1948, gasifying only 4 million tons of coal per year and the process extended to the cleaner fuels, anthracite and coke(1). Today, in the United States only a few bituminous coal gas producers exist and these have been placed in mothballed and perhaps standby positions.

The decline of manufactured gas production has been attributed to a number of factors, most prominent of which was the advent of low cost and versatile hydrocarbon fuels; fuel oil and natural gas as developed from domestic reserves and new pipeline transportation systems.

It is reasonable to claim that America became complacent over cheap natural hydrocarbons and did not pay great heed to those concerned with the eventual depletion of these fuels. Only token efforts of research and national interest were applied to the objectives of meeting fuel requirements and standards that could be expected for the 1970's and 1980's. During the 1950's and 1960's only a small number of new young technologists could be convinced of the challenges offered by the mineral industry fields. Only a small portion of these were inclined to have interest in smelly coal gas developments, an area which then had signs of becoming obsolete. In view of the foregoing, it appears as if the present day coal-to-gas technologists will have to "play catch-up."

FIXED BED GASIFICATION

The production of low BTU gas from coal is a broad topic of coal gasification which ranges from the long established coke oven practices to the more sophisticated high pressure fluo-solid reactions of coal, oxygen enriched air, and water. A general classification of coal gasification processes has been qualified by Von Fredersdorff and Elliot and their listing has been expanded with further items as presented in Table 1(2). The subject of this presentation will largely concern production of low BTU gas from coal by classical and improved technologies listed as the initial items in the outline of Table 1. This involves fixed bed gasification of coal autothermally converted by a countercurrent air-stream draft in an atmospheric producer disposing of dry granular ash.

A generalized version of this gasification process is illustrated in Figure 1 which shows reaction zones in a section of a producer and the corresponding temperature-composition gradients when a solid fuel is converted into low BTU producer gas. Sized and selected qualities of coal are charged and distributed to the top of a cylindrical shaft and descend countercurrently to a forced air-steam blast. The fixed bed designation refers to fixation of the top and bottom surfaces of the bed with respect to space while the continuously applied charge moves downward and converts into gas and ash. The forced draft enters through the grates and exchanges heat with ash prior to combustion within the narrow peak temperature oxidation zone. Herein oxygen combines with carbon to form CO_2 causing the greatest evolution of heat in the process and control is exercised to prevent excessive ash fusion by appropriate steam additions. Preheated steam and CO_2 from the oxidation zone cause endothermal reactions in the reduction zones which give rise to production of the main fuels of producer gas, carbon monoxide, and hydrogen.

Hot reduced gases from the reduction zones provide heat for pyrolysis reactions and drying-preheating within the topmost zone of the charge. Pyrolysis largely involves thermal cracking of the volatile hydrocarbonaceous matter of coal and tars. Large molecular weight compounds are thermally degraded into lighter, smaller, and more volatile constituents as a wide range of compounds comprising soot, tars, light oils, tar acids, and noncondensable gases. The degradation brings about production of methane, hydrogen, water, carbon, and carbon oxides.

The coexistence of all cited reactions of Figure 1 within specific zones is governed by reactivities of the fuel and chemical equilibria limitations. The distinct zones illustrated in Figure 1 are shown only for purposes of simple isolation. For instance, the reversal of CO_2 reduction of the Boudouard reaction can cause carbon deposition in the upper cooler zones of pyrolysis. Also, possibilities can exist for the methanation reaction of carbon and carbon monoxide reacting with hydrogen to a very limited extent. During gasification organic and pyritic sulfur of coal is largely converted to gaseous forms such as H_2S, CS_2, COS, and various light mercaptans. These are brought about by oxidation-reduction reactions and direct reactions with labile sulfur from the pyrolysis of pyrite. Sulfides of coal ash are oxidized by the initial air-steam draft and the sulfur oxides originating in this zone and the oxidation zone are subsequently reduced in the reduction zones to high portions of hydrogen sulfide.

Evolution of tars, condensable oils, and carbonaceous soot within the pyrolysis zone contributes to problems of bed permeability and depositions within the off-gas ducts. Use of the producer gas in a hot raw state (1100-1500 ^{o}F) has necessitated measures for coping with duct and burner problems. Condensables and other particulates can be removed, however, by cooling, condensation, scrubbing, and precipitation. These provide cold clean gas and necessitate disposition plans for the oily and aqueous by-products. Clean producer gas can be further purified by removal of gaseous suflur compounds through use of a number of removal and recovery schemes, new and old, some of which are listed in Table 2.

Thermal efficiencies of gas production systems are defined as the percentage of heat from the solid fuel which reports in the sensible and latent heat of the gas. Hence hot raw gas producers show efficiencies of about 90 percent and cold clean gas producers using bituminous coal have efficiencies of about 70 percent which increase to about 85 percent with coke and anthracite.

GAS PRODUCERS

A wide variety of gas producer designs were constructed during the early 1900's based largely on the original concepts of Bischof, Ebelman, Ekman, and Siemens. Since the initial inventions about 150 different organizations manufactured gas producers(3). Some specific designs available as early as 1907 are listed as follows:

Amsler	Siemens
Swindell	Wellman
Smythe	Fraser-Talbot
Taylor	Morgan
Wood	Loomis
American Furnace	Wile

These producers operated under forced draft. During the same time period there were about an equal number of designs which functioned under induced draft. Through evolution of design and market acceptance only a few producer gas units survived into the 1920's, 1930's, and 1940's. Some prominent units were the Morgan, the Wellman-Hughes, the Wood, the Semet-Solvay-Koller, the Koppers-Kerpely, and the Wellman-Galusha. The latter is the only producer to survive into the 1950's-1970's with some current applications involving production of special high CO gases for chemical purposes. Features of some of the producers are illustrated in Figures 4, 5, and 6 which are described as follows:

1. Figure 2 - Wellman-Hughes Gas Producer (4)

   This was a refractory-lined and water sealed unit with rotating shell and oscillating agitator for gasifying bituminous coal.

2. Figure 3 - Koppers-Kerpely Gas Producer (5)

   This unit had refractory and water cooled walls which were stationary components and it used a rotary water sealed ash removal system. This producer was largely used for gasifying coke.

3. Figure 4 - Wellman-Galusha Gas Producer (3)

   This unit is designed for gasifying all forms of solid fuels including bituminous coal, anthracite, coke, and charcoal. The producer consists of a choke filled hopper, stationary water cooled walls which provide humidity for the blast, rotary grates, and a rotary agitator used for inducing controlled permeability to troublesome burdens such as swelling varieties of coals. A battery of 14 Wellman-Galusha producers constructed in a gas plant is shown in Figure 5.

Producer gas was widely developed for open hearth type furnace applications which benefited from hot raw gas and preheated air from regenerative sections. The open hearth steelmaking and glassmaking furnaces are typical in this respect, commonly using hot raw producer gas generated from a battery of producers. After cooling and cleaning systems were developed, producer gas was extended into applications for smaller industrial furnaces and gas engines. Cleaned and purified producer gas was applied as a fuel blend for town gas plants and chemical-metallurgical industries used producer gas for synthesis and reduction applications.

FUELS

Production of low BTU gas from anthracite and coke does not necessitate extensive cleaning because there are no significant pyrolysis reactions. As a result, these fuels have extensive acceptance for production of producer gas because of the lower capital and conversion cost factors inherent with low volatile fuels.

Gas-solid reactions in producers are dependent on uniform charge permeability. For this reason closely sized fuels have been preferred and in some cases they have been required. Producers using bituminous coals usually use nut and egg sizes and those using anthracite and coke have generally used buckwheat and rice sized charge.

Both swelling and nonswelling qualities of bituminous coal have been successfully gasified in commercial applications and specially designed mechanical agitators have been used for maintaining bed permeability with troublesome burdens. Various types of agitators have been designed to allow producers to cope with coals having high free-swelling indices and unusual softening-agglomerating characteristics. These coals are prevalent in the eastern and midwestern coal regions of the United States.

The composition of producer gas is dependent on the quality of volatile matter in the fuel, the reactivity of the fuel, and to a certain extent, the ash fusion characteristics which influence the requirement of steam. Table 3 provides general data on composition of various manufactured gases including low BTU producer gas made from four different types of fuel.

COSTS

Costs for production of producer gas have been presented by several articles based on factual records and projections[1,6,7]. Specific costs obviously depend on items such as objectives, rates, quality of operations, and quality of raw materials, all of which are subject to change with time. Table 4 presents conversion costs of coal as derived from different producer gas plants operating at different periods of time producing hot raw low BTU gas. It is noteworthy that a span of 17 years did not indicate a marked change of costs. However, unless there is a marked improvement of technologies, it can be expected that the escalation of labor rates, fuel rates, and environmental requirements will cause future costs to increase. For instance, the data of the 1965 report indicated that the 43¢ per million BTU for hot raw gas would increase to about 55¢ for cold clean gas and this study (1965) did not account for removing sulfur to the levels now expected to be necessary for 1974.

PRESSURE APPLICATIONS

The incentive for production of hydrocarbons and high BTU gas from coal justified development of the oxygen blown pressure producer designed to operate under about ten to twenty atmospheres of pressure. The Lurgi high pressure gas producer was developed in Germany in the 1930's to utilize the noncaking brown coals. A number of similar applications have been extended since this early development. McDowell-Wellman Engineering Company constructed the retort and mechanical components of the high pressure pilot plant gas producer for the U. S. Bureau of Mines which was specifically designed for gasification of the swelling type coals of the United States. The Lurgi unit also has been tested for this purpose. Diagrams of these two types of producers are shown in Figures 6 and 7[8,9].

ASPECTS OF FUTURE COMMERCIALIZATION

Production of clean, low cost, low BTU producer gas for future industrial purposes will depend on achieving a number of process improvements. This is especially important if the gas is to be made from a wide variety of fuels with varying values. Some aspects of gas production which require attention or improvement are cited as follows:

1. Fuel Sizes

   The gasification system should be developed to accept a wide variety and range of fuel sizes rather than the more costly specific coarse size fraction.

2. Fuel Qualities

   The machinery and processing systems should be improved for broadly accepting (a) weak structured coals which tend to degrade during gasification and (b) the severe high swelling fuels which tend to strongly agglomerate during gasification.

3. By-product Utilization

   Utilization of all by-product liquids including tars, oils and aqueous liquors along with solid wastes will become of increasing importance for all gasification processes and proper approaches should be developed for recycling the by-products to the processing system or isolation and upgrading of by-products for market purposes.

4. Environmental Requirements

   It can be expected that environmental requirements for more complete control will continue to increase and extensive processing provisions will be required for (a) production of high purity products from the processing system and (b) design of appropriate safeguards from accidental or designed venting of gases and liquids from the system.

5. Unit Capacities

Increasing costs of labor for operations and maintenance and increasing costs for materials of construction and improvement of thermal efficiencies will direct processing systems to high unit capacities and capabilities of treating high tonnages with single or small multiples of large machines rather than the large numbers of small machines.

6. Usage

Use of clean low BTU gas in large quantities for boiler fuel and large industrial furnace applications will require renewed attention to aspects of gasification which combine large capacity units with high availability factors and wide turndown capabilities.

PROCESS DEVELOPMENTS

The six cited items which deserve improvement for growth of the producer gas industry indicate merit to the design of larger diameter units as well as design of systems for charge preparation and recycle of by-products. Expansion of the peak 10-ft. diameter design for atmospheric producers will bring increasing attention to factors such as (1) charge preparation for uniformity of burden column permeability, (2) uniformities and control of ash removal, (3) control of the specific reaction zone levels, and (4) control of bed agitation for mechanically inducing bed permeability. The current and future designs can markedly benefit from charge preparation schemes of "beneficiation charge" that would integrate precarbonizing-agglomerating and recycling with fixed bed gas production. Research and pilot plant work in this area appear to be justified. Such schemes might parallel the successful evolution of the iron blast furnace smelting practices which evolved with the largest units in the following approximate order of peak blast furnace capacities.

Era	T/D of Iron
1940's	1,500
1950's	3,000
1960's	6,000
1970's	10,000

History reveals that these increases were attained by developments of both charge preparation and furnace enlargement.

Charge preparation for modern blast furnace practices include (1) production of strong durable sized coke from coal and (2) production of strong durable sized ore agglomerates from a blend of ores, fluxes, and plant recycles such as dusts and sludges. Iron ore agglomerates are produced as close sized structures of sinter or pellets prepared largely by continuous traveling grates. These machines are of a Dwight-Lloyd type and have enormous unit capacities. Individual machines of a modern plant have sinter production capacities which exceed 12,000 T/D of beneficiated charge for blast furnaces. An artist's diagram of a sinter plant is shown in Figure 8.

The sintering process involves preparation and conversion as a continuous series of operations (10). The initial preparation consists of proportioning and blending of fine ores and fluxes with about 5 percent coke breeze and moisture to form a nodular textured burden. This is continuously charged to the sintering machine as a thin bed supported on the moving grates. Some of the larger Dwight-Lloyd machines have a grate hearth area of about 15 feet wide and 350 feet long. The raw material is flame ignited after charging to the grates and an induced draft performs combustion, calcination, partial fusion, and cooling to form a coherent cellular structured sinter cake. This is subsequently crushed and graded into an appropriate size for the blast furnace and the fines are recirculated.

The traveling grate process for beneficiating or converting coal for gas production is a subject of current patents and research at the Dwight-Lloyd Research Laboratories of McDowell-Wellman Engineering Company. A general concept involves preparation of a thin bed comprised of nodulized coal and recycle materials followed by traveling grate processing of high temperature pyrolysis-gasification which evolves low BTU gas, liquids and agglomerated residue of coke-char composition suitable for final gasification. Figure 9 illustrates two simplified species of the Dwight-Lloyd traveling grate processes for converting coal. One of these involves combustion of oil or gas for sustaining operations and the other involves combustion of fixed carbon. As the charge enters the pyrolysis or carbonizing zone it becomes intercepted by hot gases which cause coking and gasification of the thin bed. Cooling and condensation is effected by both the lower incremental layers of charge and the heat sink. These enable coal gases to be recycled to the cooling zone which in turn provides preheated media for carbonizing.

Tests which simulate the time - temperature - draft flow conditions of the aforementioned traveling grate processes have been performed with a wide variety of fuels ranging from lignites to highly coking coals. Agglomeration and permeability characteristics of the bed for such tests were controlled by use of recycle materials. In cases of treating coals by the pelletizing process, the recycle materials can comprise portions of the green pellet as well as portions of the bed to maintain consistent bed permeability for uniform processing operations.

Table 5 presents resume data on conversion of a strongly caking coal into gases, liquids and pelletized coke using combinations of the pelletizing process and the traveling grate carbonizing processes illustrated in Figure 9. A graphical portrayal of the thermal history of the bed within the traveling grate pelletizing-carbonizing process for both species is shown in Figures 10 and 11. The data show both processes to be capable of converting coal into durable pellet coke for final gasification in fixed bed gas producers.

A liquid sealed circular Dwight-Lloyd machine is involved in this development and Figure 12 illustrates a rendition of this unit. Current designs on the order of 3,000 square feet and greater have the potential of converting more than 1,000,000 T/Yr of coal into hardened coke-like masses with about 50 percent of the fuel evolved into gaseous and liquid fractions. These can be recycled or combined with producer gas made from a final stage of gas production using either an enlarged shaft furnace or traveling grate. Gas desulfurization can be applied to the recycle stream to assist desulfurization of the char or it can be applied to the final vented or combined gas streams.

Charge preparation schemes such as the traveling grate - precoking processes can be integrated with an upgraded and enlarged version of fixed bed gas producers to meet the challenges of making clean, low cost, low BTU gas from coal. Approaches such as this could welcome offgrade coals back into our energy picture.

ACKNOWLEDGEMENTS

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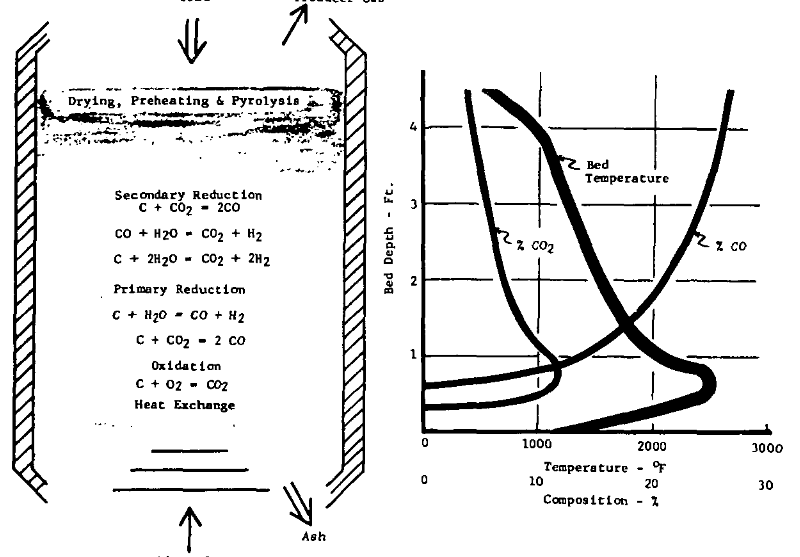

Figure 1 - Section and Gradients for Fixed Bed Gas Production

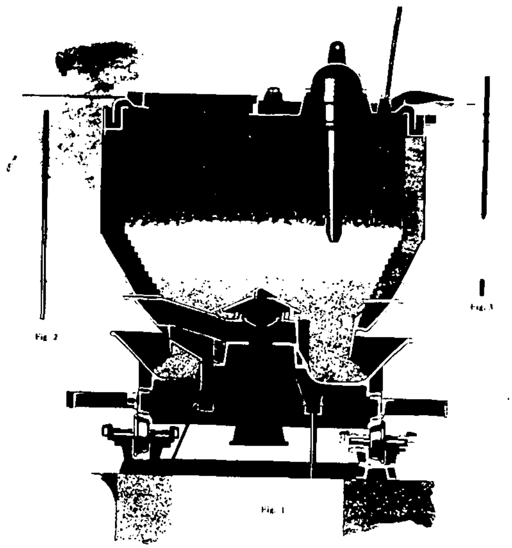

Figure 2 - Wellman-Hughes Gas Producer

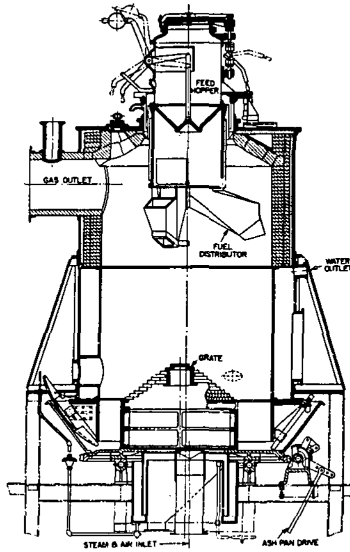

Figure 3 - Koppers-Keperley Gas Producer

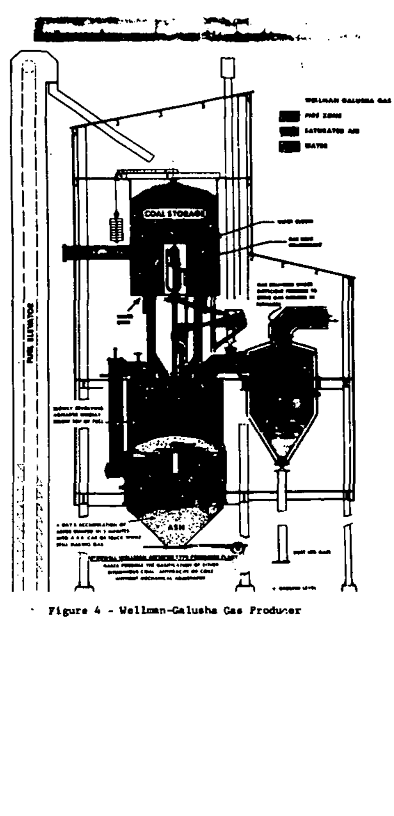

Figure 4 - Wellman-Galusha Gas Producer

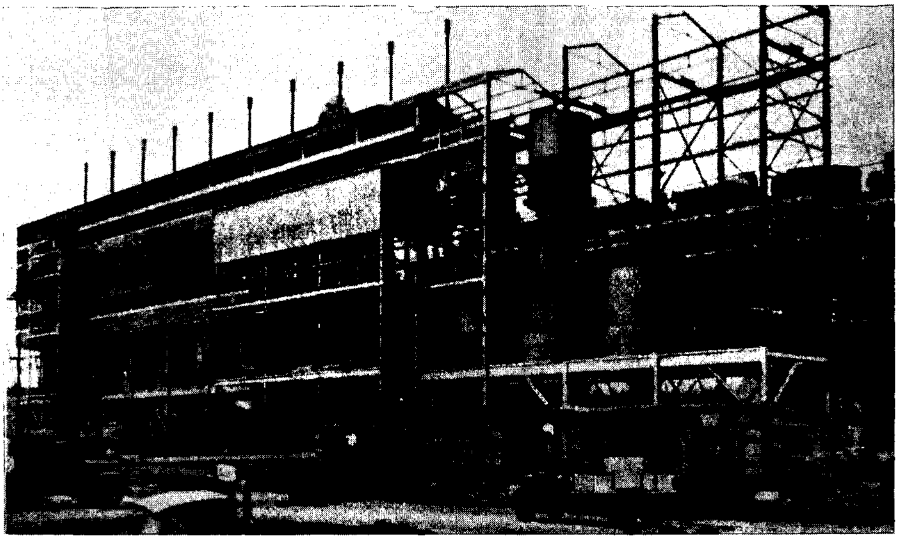

Figure 5 - A Battery of Fourteen Producers
Within a Wellman-Galusha Gas Plant

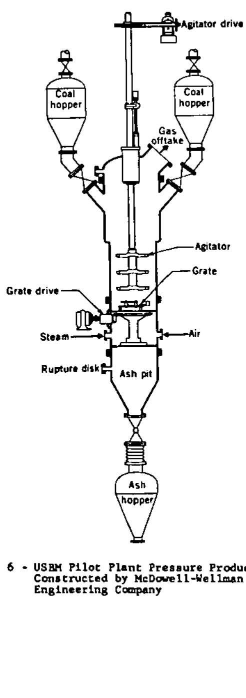

Figure 6 - USBM Pilot Plant Pressure Producer
Constructed by McDowell-Wellman
Engineering Company

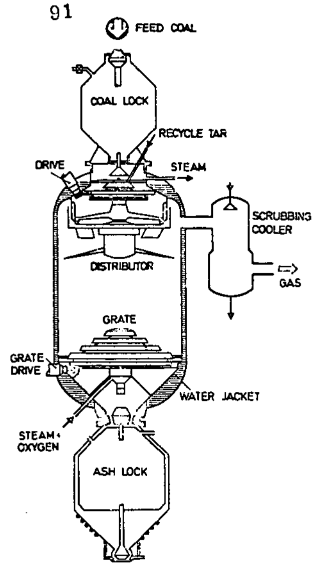

Figure 7 - Lurgi Pressure Producer of Lurgi Mineralöltechnik GmbH

Figure 8 - Iron Ore Sintering Plant

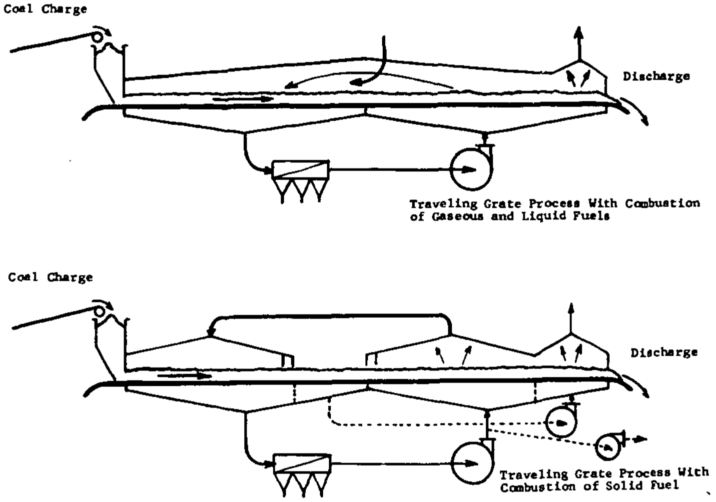

Figure 9 - Dwight-Lloyd Traveling Grate Processing Systems for Carbonizing-Gasifying Coal

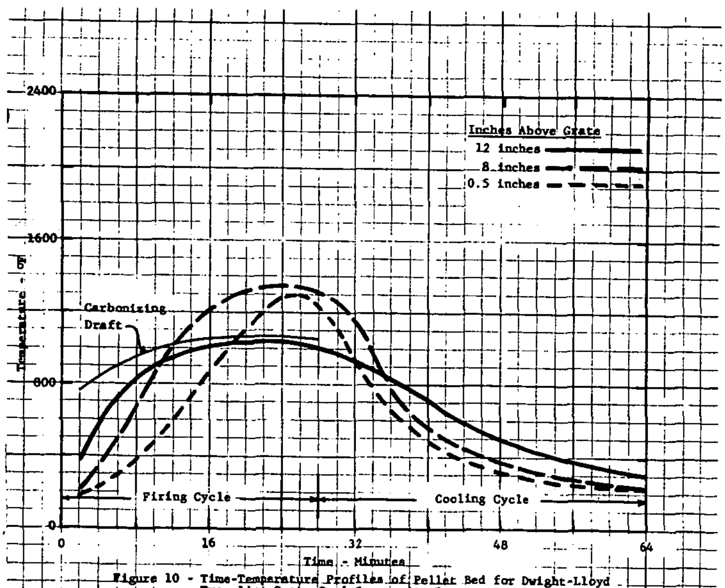

Figure 10 - Time-Temperature Profiles of Pellet Bed for Dwight-Lloyd Traveling Grate Coal Conversion Process.

Combustion of Recycle Gases and Liquid Fuels

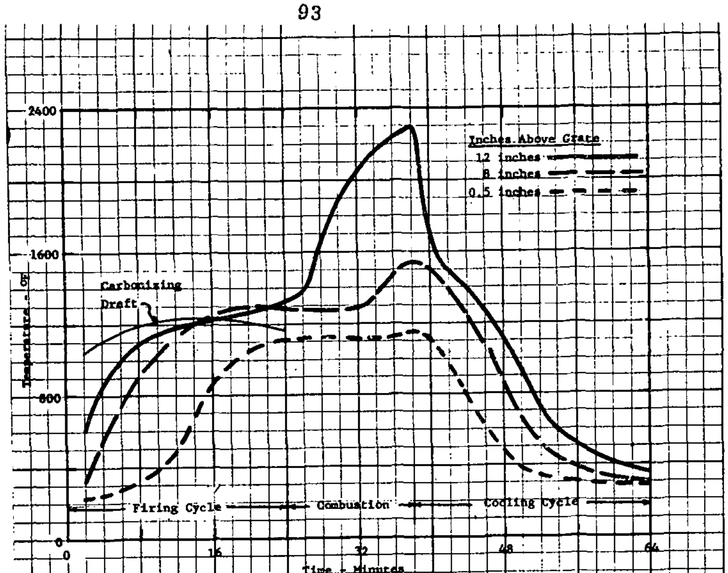

Figure 11 - Time-Temperature Profiles of Pellet Bed for Dwight-Lloyd Traveling Grate Coal Conversion Process.
Combustion of Bedded Fixed Carbon Fuel

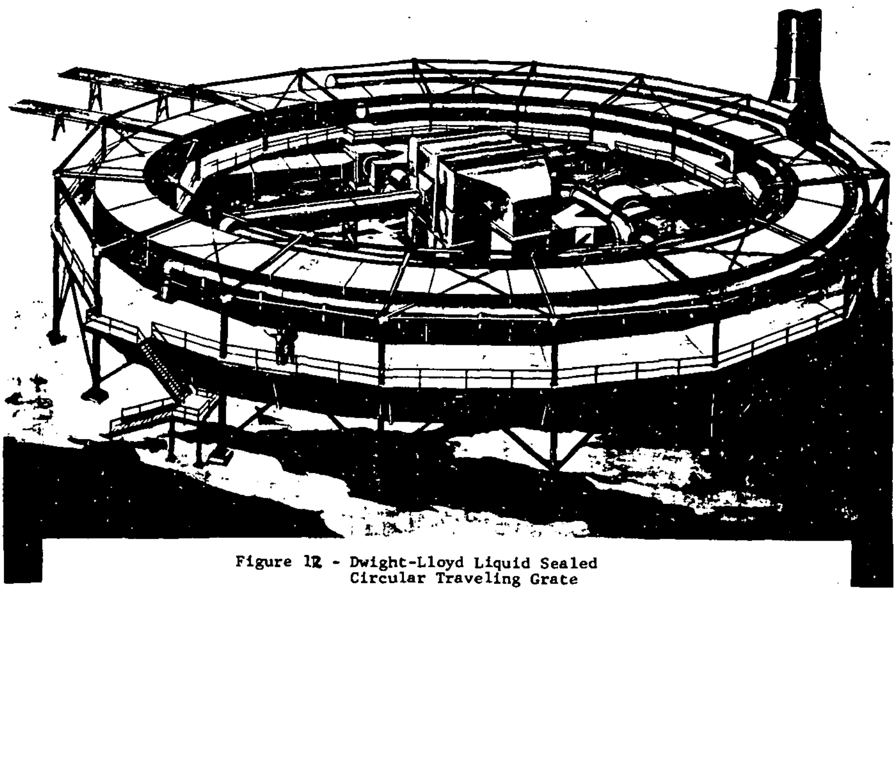

Figure 12 - Dwight-Lloyd Liquid Sealed Circular Traveling Grate

Table 1

CLASSIFICATION OF GASIFICATION PROCESSES

I. Method of Supplying Heat
   A. Internal (direct)
      1. Autothermic
      2. Cyclic
      3. Fluids or solids
   B. External (indirect)
      1. Transferred through walls
II. Method of Reacting
   A. Fixed bed
   B. Fluidized bed
   C. Suspension or entrainment
III. Flow of Reactants
   A. Countercurrent
   B. Concurrent
IV. Gasification Media
   A. Air with steam
   B. Oxygen with steam
   C. Enriched air with steam
   D. Hydrogen
   E. Spent air with generated gases
V. Ash Disposition
   A. Dry and granular
   B. Liquid as slag
VI. Conditions of Reaction
   A. Atmospheric pressures
   B. Elevated pressures

Table 2

SOME SULFUR REMOVAL SYSTEMS
FOR
PURIFYING LOW BTU GAS

Process System	Principal Reagent
Iron box	Ferric oxide and hydroxide
Vacuum carbonate	Sodium carbonate
Ferrox	Ferric hydroxide
Amine absorption	Mono and diethanolamine
Thylox	Sodium thioarsenate
Hot potassium carbonate	Potassium carbonate
Appleby-Frodingham	Ferric oxide
Stredford	Sodium ammonium vanadate

Table 3 - Comparison of Various Typical Gases

Analysis		Water Gas (Coke)	Carburetted Water Gas	Coke Oven Gas	Typical Wellman-Galusha Producer Gas (under full load operating conditions): Bituminous	Anthracite	Charcoal	Coke
Carbon Monoxide	CO	37.0	32.0	6.3	28.6	27.1	29.5	29.0
Hydrogen	H_2	47.3	34.0	46.5	15.0	16.6	12.0	10.0
Methane	CH_4	1.3	15.5	32.1	2.7*	0.5*	0.5*	0.7*
Ethane	C_2H_6							
Propane	C_3H_8							
Butane	C_4H_{10}							
Ethylene	C_2H_4		4.7	3.5				
Benzene	C_6H_6		2.3	0.5				
Carbon Dioxide	CO_2	5.4	4.3	2.2	3.4	5.0	3.0	3.5
Oxygen	O_2	0.7	0.7	0.8	0.0	0.0	0.0	0.0
Nitrogen	N_2	8.3	6.5	8.1	50.3	50.8	55.0	56.8
Common Properties:								
B.T.U. (a) Gross		286	532	572	168.13	146.2	139.0	132.9
(b) Net		262	492	512	157.90	137.4	132.5	127.2
Ratio of Net to Gross B.T.U.		.916	.925	.895	.939	.940	.953	.957
Approximate Flame Temp. °F		3670	3700	3610	3200	3100	3080	3020
Cu. Ft. Dry Air per Cu. Ft. Gas		2.10	4.51	4.99	1.30	1.09	1.04	1.00
B.T.U./Cu. Ft. Quantative Mix (a) Gross		92.3	96.6	95.5	73.1	70.0	68.1	66.4
(b) Net		84.5	89.3	88.6	68.7	65.7	65.0	63.6
Cu. Ft. Combustion Products per Cu. Ft. Gas		2.71	5.24	5.78	2.105	1.89	1.85	1.82
B.T.U. per Cu. Ft. Combustion Products (a) Gross		105.5	101.5	99.0	80.0	77.4	75.1	73.0
(b) Net		96.7	93.9	88.6	75.2	72.7	71.6	69.9
Specific Gravity		0.57	0.67	0.44	0.84	0.85	0.88	0.90

*Methane content increases with percent volatile content

Table 4

GAS PRODUCER OPERATING COSTS
FOR
PRODUCTION OF HOT RAW GAS*

	1948 Data $/NT Converted Coal	1965 Data $/NT Converted Coal
Operating labor & supv.	$ .77	$ .61
Electrical energy	.07	.18
Steam charges	.42	
Water	.02	.29
Maintenance	.31	.29
Capital charges	.72	.85
Cost per ton of coal	$2.39	$2.22
Producer gas heat costs based on coal at 8$/T	56¢/MMBTU	43¢/MMBTU

* Data from different sources for[1,6,7]
plants using 10-ft. producers.

TABLE 5

RAW MATERIAL AND PELLET COKE PROPERTIES
(Traveling Grate Process for Conversion of Coal)

Proximate Analysis (dry basis)	Coal	Pellet Coke Gas Combustion	Pellet Coke Carbon Combustion
Volatile matter	34.5%	6.5%	4.8%
Fixed carbon	52.1%	68.7%	67.0%
Ash	13.4%	24.8%	28.2%
Free swelling index	6	0	0
Cold Strength			
Point contact			
Crush load	50 lb	100 lb	150 lb
Coke Tumble Test			
1 lb, 200 rev. 25 rpm, % +¼" ret.	33.0%	71.0%	80.0%
Size Analyses (feed and product)			
Ground coal			
-20M +100M	13.5%	-	-
-100M +200M	31.5%	-	-
-200M	55.0%	-	-
Fired pellets			
-1" +3/4"	-	3.6%	5.4%
-3/4" +1/4"	-	92.3%	91.1%
-1/4" +0	-	4.1%	3.5%